Heavy-ion SEE at Elevated Temperatures Test Report for the THS4304 Wideband Operational Amplifier

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I. Introduction

The purpose of this study is to examine heavy-ion-induced single event effects (SEEs) of the THS4304 Wideband Operational Amplifier manufactured by Texas Instruments.

II. Device Description

The THS4304 is a commercial off the shelf high-speed operational amplifier designed for use in high-speed analog signal-processing chains operating with a 5 V power supply. The part is based on silicon-germanium BiCMOS process and features a maximum bandwidth up to 3 GHz. The test/part information is listed in Table 1.

Table 1. Test and part information

Generic Part Number	THS4304DBVT
Package Marking	AKW
Manufacturer	Texas Instruments
Lot Date	October, 2004
Quantity tested	2
Part Function	Operational amplifier
Part Technology	Silicon-Germanium BiCMOS
Package Style	5-pin SOT-23
Test Equipment	Power supply, RF generator, high-speed oscilloscope
Test Engineer	Anthony Phan

III. Test Facility

Facility: Texas A&M University Cyclotron SEE Test Facility
Beam Energy: 15 MeV/amu
Flux: 1×10^4 to 1×10^5 particles/cm^2/s
Fluence: $\leq 2 \times 10^7$ particles/cm^2
Ions:

Table 2. Heavy ion information.

Ion	Total Energy (MeV)	LET (MeV·cm^2/mg)	Range in Si (µm)
Ne	300	2.5	316
Cu	944	17.8	172
Ag	1634	38.5	156

IV. Test Method

Figure 1 shows the test circuit designed for a non-inverting configuration with a gain of 2 V/V (6 dB). The -3 dB bandwidths are approximately 480 MHz for V_{out} = 1 V and 1 GHz for V_{out} = 100 mV. Both large and small signal conditions were tested for different frequencies. A block diagram schematic of the test setup is shown in Figure 2. A LabVIEW program controlled the input signal characteristics and the power supply. The program also captured the SETs and monitored the input and supply currents.

The irradiation was performed at normal incidence for each ion species. Incident angle irradiation (45^{o} and 60^{o}) was also performed for selected ion species. Each part was irradiated until 100 transients are observed, or single event latchup occurs, up to a fluence of 2×10^{7} ions/cm^{2}.

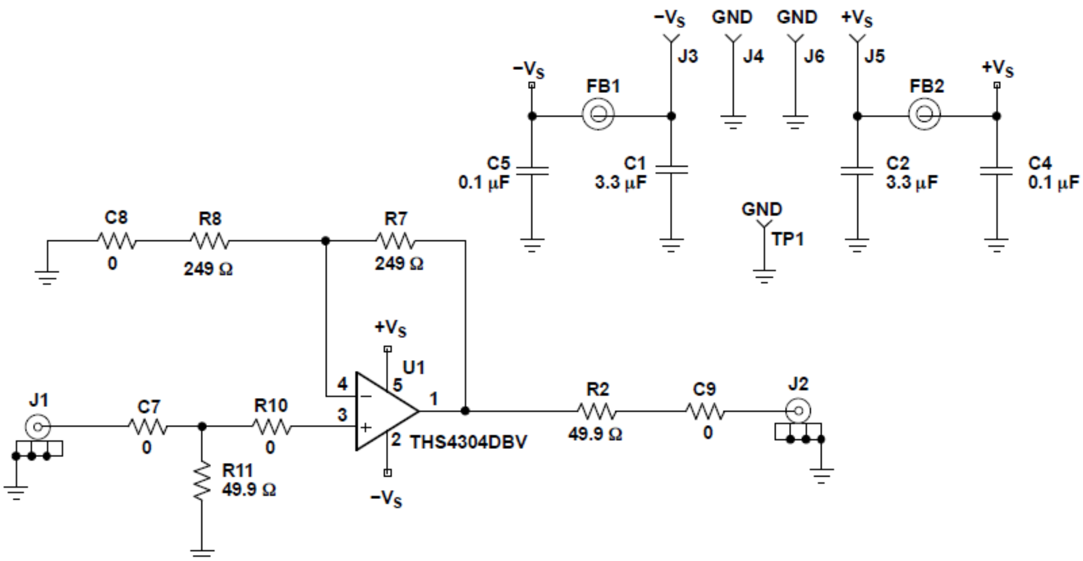

Figure 1. Application for a non-inverting with split power supply circuit configuration.

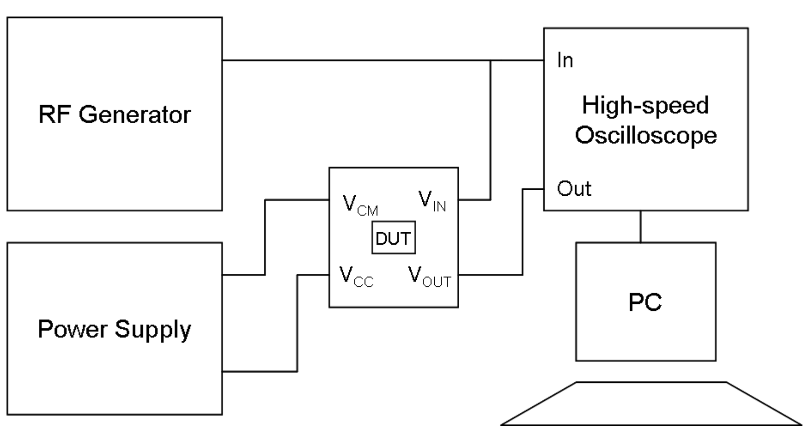

Figure 2. Test setup block diagram.

Test Conditions

Test temperature:	Ambient temperature
Operating frequency:	1 MHz − 1 GHz
Supply voltage:	$+V_S$ = 2.5 V and $-V_S$ = - 2.5 V
Input Voltage:	Small signal: 100 mV_{pp} sine wave
	Large signal: 1 V_{pp} sine wave
Parameter:	(1) SETs were examined until 100 transients are observed and acquired or up to a ion fluence of 2×10^7 ions/cm^2.
	(2) Single event latchups were also examined up to a ion fluence of 2×10^7 ions/cm^2.
Data format:	Spreadsheet
Beam hours:	**8**

V. Results

Two devices were irradiated with 15 MeV/amu heavy ion beams. We found that the devices were susceptible to SETs down to the lowest LET of 2.2 MeV·cm^2/mg. We also observed that the SET LET threshold (LET_{th}) and error cross sections are dependent on the LET as well as device operating frequency and input signal magnitude. Figure 3 summarizes the SET error cross section characteristics with different LET values and operating conditions for the two parts.

The SET LET threshold and error cross section varied with frequency for large signals. The SET LET_{th} for a 1 V_{pp}, 200 MHz input signal is less than 4.4 MeV·cm^2/mg; at 100 MHz the LET_{th} is less than 15.6 MeV·cm^2/mg; at 10 MHz the LET_{th} is less than 31.2 MeV·cm^2/mg. We observed very few SETs at the lowest LET for the 1 MHz signal. Six errors were captured for DUT2, while no errors were observed for DUT1 at 15.6 MeV·cm^2/mg. So the LET thresholds, particularly at low frequencies (1 MHz), may be influenced by statistical variations. Nevertheless the cross section values from DUT2 and DUT1 are similar for other LET values. Therefore we show only data from DUT1 for clarity. The maximum error cross sections at the highest LET of 67.2 MeV·cm^2/mg are 5.25×10^{-6} cm^2 and 9.5×10^{-7} cm^2 for a large signal at 100 MHz and 10 MHz respectively; we see an increase of approximately ×5 from 10 to 100 MHz.

On the other hand the SET LET_{th} and cross sections for small signal (0.1 V_{pp}) showed negligible frequency dependence. We include the cross section data for the 100 MHz signal in Figure 3. The LET threshold is less than 2.2 MeV·cm^2/mg. The error cross section at an LET of 67.2 MeV·cm^2/mg is approximately 1.37×10^{-5} cm^2.

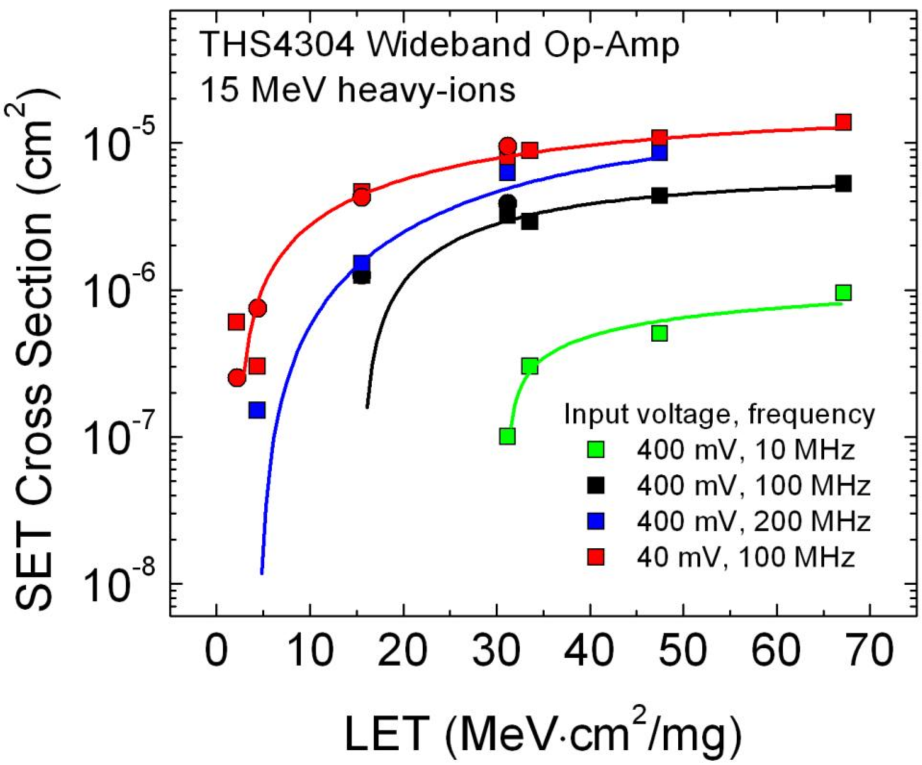

Figure 3. SET error cross sections vs. LET for different operating conditions.

The SET characteristics are shown in Figure 4 – 10. The SET characteristics remain similar at different LET values for a given input voltage and frequency. However the transients vary in shape for different input voltages and frequencies. Figures 4 – 7 show SETs for a large signal at frequencies 10, 100, and 200 MHz. The SETs at 10 MHz are small glitches. The SETs at 100 MHz generally distort half a waveform cycle; the transient usually flattens the peak. The SETs at 200 MHz distorts the waveform for several cycles; the transient flattens some peaks while enlarging some peaks to saturation. The SET characteristics for LET = 15.6 and 67.2 MeV·cm^2/mg are similar for the same operating conditions, as shown in Figures 5 and 7. The small signal SET characteristics at frequencies 1, 10 and 100 MHz are shown in Figure 8 – 10. The transients at 1 and 10 MHz are voltage spikes that affect half of the waveform cycle. The worst case transients at 100 MHz disrupts one cycle of the waveform, as shown in Figure 10. The input currents varied from approximately 17.9 mA to 19.5 mA throughout the irradiation. The variations are due to changes in input voltages. No single event latchups were observed.

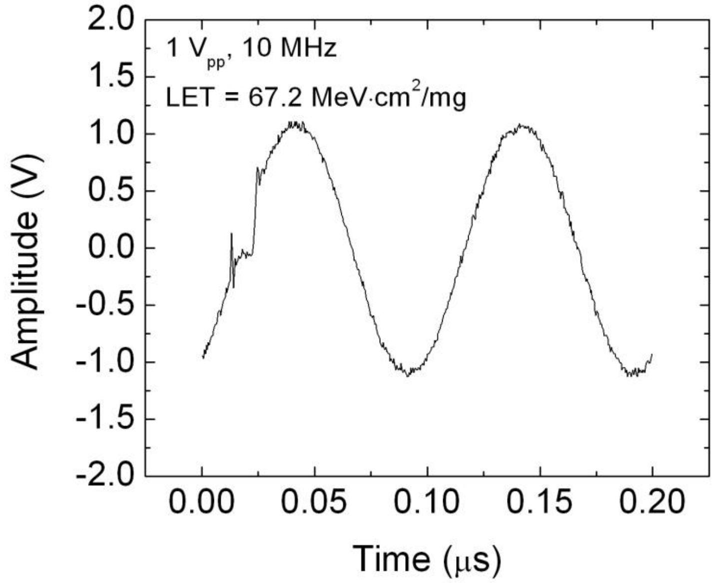

Figure 4. SET characteristics for the THS4304 with V_{in} = 1 V_{pp} and frequency = 10 MHz at LET = 67.2 MeV·cm^2/mg.

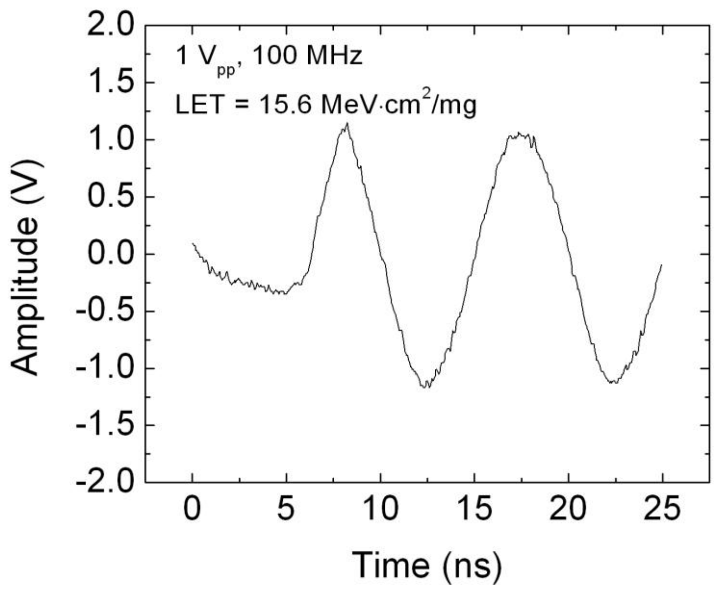

Figure 5. SET characteristics for the THS4304 with V_{in} = 1 V_{pp} and frequency = 100 MHz at LET = 15.6 MeV·cm^2/mg.

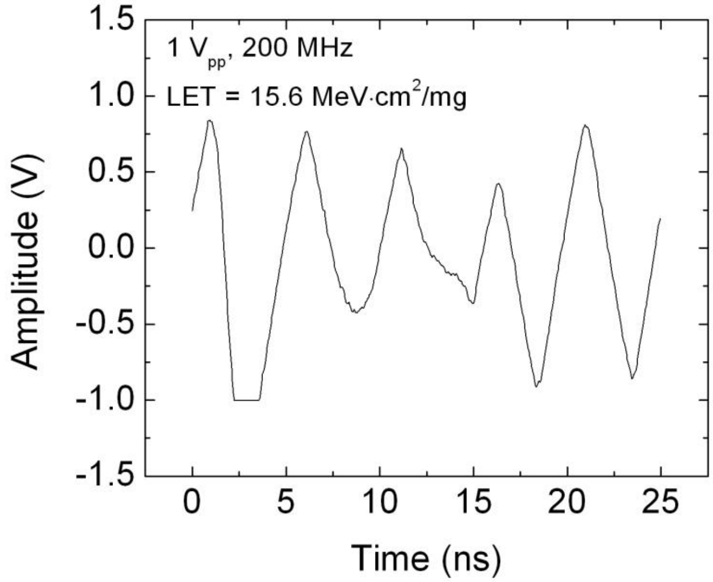

Figure 6. SET characteristics for the THS4304 with V_{in} = 1 V_{pp} and frequency = 200 MHz at LET = 15.6 MeV·cm^2/mg.

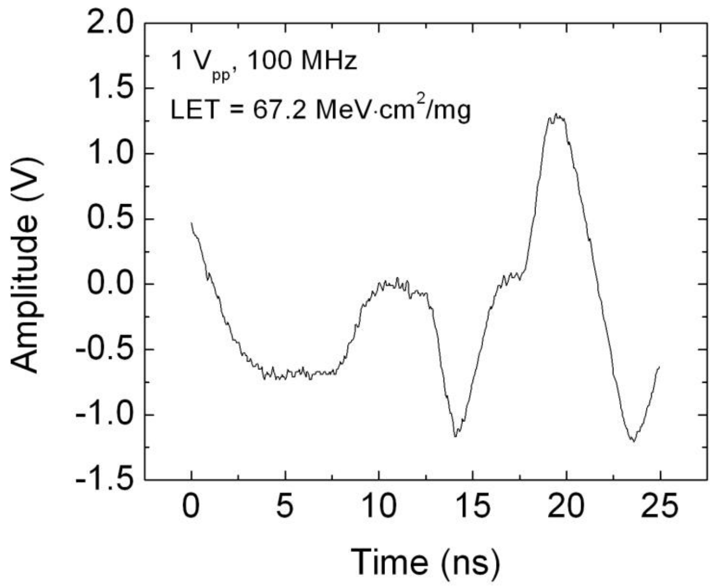

Figure 7. SET characteristics for the THS4304 with V_{in} = 1 V_{pp} and frequency = 100 MHz at LET = 67.2 MeV·cm^2/mg.

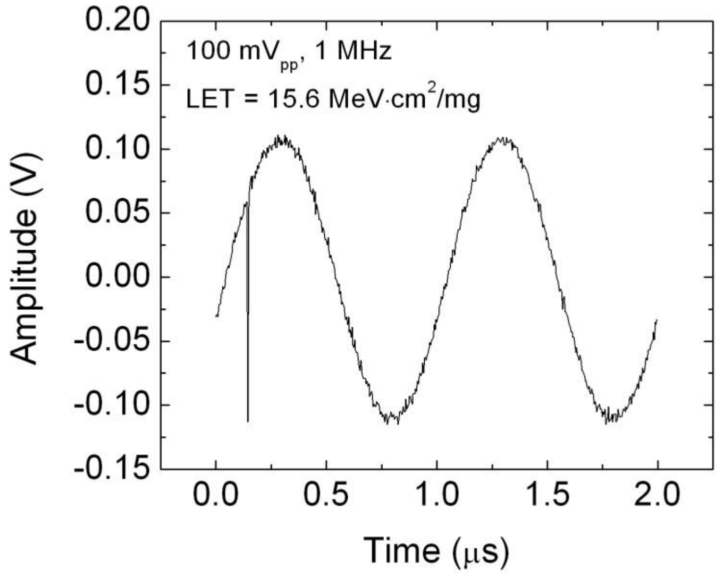

Figure 8. SET characteristics for the THS4304 with V_{in} = 100 mV_{pp} and frequency = 1 MHz at LET = 15.6 MeV·cm^2/mg.

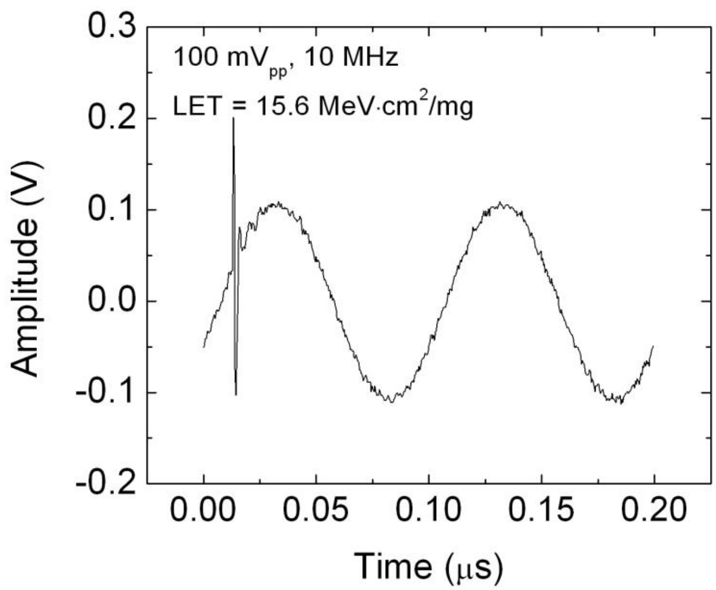

Figure 9. SET characteristics for the THS4304 with V_{in} = 100 mV_{pp} and frequency = 10 MHz at LET = 15.6 MeV·cm^2/mg.

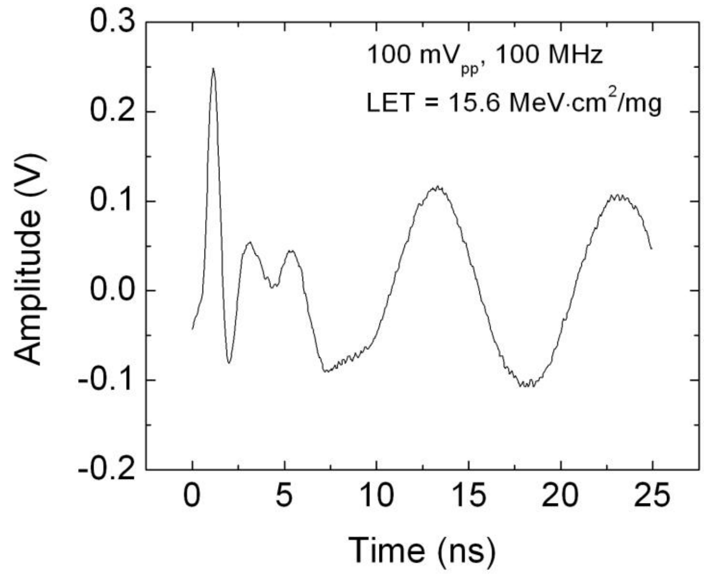

Figure 10. SET characteristics for the THS4304 with V_{in} = 100 mV_{pp} and frequency = 100 MHz at LET = 15.6 MeV·cm^2/mg.

VI. Conclusions

The THS4304 wideband op-amp is susceptible to heavy-ion-induced single event transients. The SET LET thresholds and error cross sections are dependent on the input voltage and frequency. In large signals (V_{in} = 1 V_{pp}), the SET LET threshold is less than 4.4, 15.6, and 31.2 MeV·cm^2/mg, for 200, 100, and 10 MHz waveforms, respectively. The maximum error cross sections appear to increase linearly with LET. For small signals (V_{in} = 100 mV_{pp}), the SET LET thresholds and cross sections are similar for different frequencies. The LET threshold is less than 2.2 MeV·cm^2/mg. The SET characteristics are similar for different frequencies in both the large and small signals. The transients are most significant at the higher frequencies (100 and 200 MHz signals), where the waveforms are disrupted for 1 cycle to several cycles. The part did not exhibit a single event latchup.

VII. Appendix

Run	DUT	Vin (mV)	Frequency (MHz)	Ion	LET ($MeV \cdot cm^2/mg$)	Angle (deg)	Effective LET ($MeV \cdot cm^2/mg$)	Flux (ions/cm2/s)	TID (krad)	Fluence (ions/cm2)	SETs	Cross-Section
1	1	400	1	Cu	15.6	0	15.6	1.00E+04	1.5	5.00E+06	0	0
2	1	400	1	Cu	15.6	0	15.6	1.50E+05	4.0	1.00E+07	0	0
3	1	400	10	Cu	15.6	0	15.6	1.50E+05	9.0	2.00E+07	0	0
4	1	400	100	Cu	15.6	0	15.6	1.50E+05	14.0	2.00E+07	25	1.25E-06
5	1	400	200	Cu	15.6	0	15.6	1.10E+05	19.0	2.00E+07	30	1.50E-06
6	1	40	200	Cu	15.6	0	15.6	1.00E+05	24.0	2.00E+07	89	4.45E-06
7	1	40	100	Cu	15.6	0	15.6	1.00E+05	29.0	2.00E+07	92	4.60E-06
8	1	40	10	Cu	15.6	0	15.6	1.00E+05	34.0	2.00E+07	82	4.10E-06
9	1	40	1	Cu	15.6	0	15.6	1.00E+05	39.0	2.00E+07	111	5.55E-06
10	1	40	1	Cu	15.6	60	31.2	8.50E+04	47.7	1.74E+07	135	7.76E-06
11	1	400	100	Cu	15.6	60	31.2	7.96E+04	57.7	2.00E+07	64	3.20E-06
12	1	400	10	Cu	15.6	60	31.2	7.87E+04	67.7	2.00E+07	2	1.00E-07
13	2	400	10	Cu	15.6	0	15.6	1.00E+05	5.0	2.00E+07	6	3.00E-07
14	2	400	100	Cu	15.6	0	15.6	1.10E+05	10.0	2.00E+07	25	1.25E-06
15	2	40	100	Cu	15.6	0	15.6	1.09E+05	15.0	2.00E+07	85	4.25E-06
16	2	40	100	Cu	15.6	60	31.2	1.08E+05	23.7	1.74E+07	165	9.48E-06
17	2	400	100	Cu	15.6	60	31.2	1.04E+05	33.7	2.00E+07	77	3.85E-06
18	2	400	10	Cu	15.6	60	31.2	1.00E+05	43.7	2.00E+07	2	1.00E-07
19	2	400	10	Ne	2.2	60	4.4	1.00E+05	43.7	1.00E+06	0	0.00E+00
20	2	400	100	Ne	2.2	60	4.4	1.15E+05	45.1	2.00E+07	0	0.00E+00
21	2	400	300	Ne	2.2	60	4.4	1.10E+05	46.5	2.00E+07	27	1.35E-06
22	2	40	100	Ne	2.2	60	4.4	1.09E+05	47.9	2.00E+07	15	7.50E-07
23	2	400	200	Ne	2.2	60	4.4	1.10E+05	49.3	2.00E+07	1	5.00E-08
24	2	40	100	Ne	2.2	0	2.2	1.10E+05	49.4	2.00E+07	5	2.50E-07
25	1	40	100	Ne	2.2	60	4.4	1.37E+05	69.1	2.00E+07	6	3.00E-07
26	1	400	200	Ne	2.2	60	4.4	1.33E+05	70.5	2.00E+07	3	1.50E-07
27	1	40	100	Ne	2.2	0	2.2	1.40E+05	70.6	2.00E+07	12	6.00E-07
28	1	40	100	Ag	33.6	0	33.6	1.15E+05	78.6	1.57E+07	138	8.79E-06
29	1	400	100	Ag	33.6	0	33.6	1.07E+05	88.6	2.00E+07	58	2.90E-06
30	1	400	200	Ag	33.6	0	33.6	1.03E+05	99.3	2.00E+07	125	6.25E-06
31	1	400	10	Ag	33.6	0	33.6	9.98E+04	110.1	2.00E+07	6	3.00E-07
32	1	400	10	Ag	33.6	45	47.5	9.72E+04	125.4	2.00E+07	10	5.00E-07
33	1	400	100	Ag	33.6	45	47.5	8.79E+04	140.7	2.00E+07	87	4.35E-06
34	1	400	200	Ag	33.6	45	47.5	8.37E+04	152.2	1.51E+07	128	8.48E-06
35	1	40	100	Ag	33.6	45	47.5	9.14E+04	161.7	1.25E+07	134	1.07E-05
36	1	40	100	Ag	33.6	60	67.2	9.24E+04	172.5	1.00E+07	137	1.37E-05
37	1	400	100	Ag	33.6	60	67.2	8.77E+04	194.1	2.00E+07	105	5.25E-06
38	1	400	10	Ag	33.6	60	67.2	8.70E+04	215.7	2.00E+07	19	9.50E-07
39	2	400	10	Ag	33.6	60	67.2	1.24E+05	71.0	2.00E+07	18	9.00E-07
40	2	400	100	Ag	33.6	60	67.2	1.35E+05	89.1	1.85E+07	135	7.30E-06